CASE STUDY

Running Line-Haul Trucks on Ethanol: The Archer Daniels Midland Experience

Imagine a 55,000-pound tractor-trailer fueled by corn! If you find that hard to believe, you can ask the truck drivers for Archer Daniels Midland (ADM) what it's like. They've been piloting four trucks powered by ethyl alcohol, or ethanol, derived from corn.

In March 1992, the first fleet of ethanol-powered, heavy-duty, over-the-road trucks was put into service in an evaluation and demonstration project. The four trucks, White-GMC WIM-64T models, were equipped with specially modified Detroit Diesel Corporation (DDC) model 6V-92TA engines. These engines were rated at 300 horsepower and used E95, a fuel composed of 95% ethanol and 5% gasoline. ADM Trucking, Inc., used these E95 trucks, along with an identical truck powered by a conventional diesel engine, almost daily for deliveries in Illinois, Indiana, Iowa, and Missouri. ADM is the largest producer of ethanol in the United States. Its fleet of more than 800 heavy-duty trucks and trailers delivers agricultural products, such as ethanol, high-fructose corn syrup, and liquid carbon dioxide (CO_2), throughout the Midwest. Because ADM produces E95 at its main facility in Decatur, Illinois, the fuel was readily available for the new trucks.

The project was designed to test the feasibility of using ethanol as a fuel for large line-haul trucks. Funded by the U.S. Department of Energy (DOE) through the National Renewable Energy Laboratory (NREL), the project was managed by the Illinois Department of Commerce and Community Affairs. DOE's Alternative Fuels Data Center recorded data on the fuel use and maintenance requirements of the E95 trucks as well as similar diesel-powered trucks for comparison.

In-Use Performance

ADM Trucking assigns each truck in its fleet to a specific driver, and that driver uses the same truck every day. The five trucks in this test fleet were no exception – each was assigned to one driver. In this way, the drivers became accustomed to the vehicles and could determine whether they were running properly. Also, different drivers operate their vehicles differently. For the project, the same driver operated the same vehicle in nearly the same way each time. The trucks were all driven under the same climatic conditions to similar destinations. Therefore, changes in fuel economy, repairs, and maintenance could easily be identified.

The four E95 trucks and one diesel control truck carried liquid CO_2 to industrial users in the Midwest. Originally, additional refueling sites were planned for other ADM terminals to allow the trucks to travel interstate routes, but this idea would require major driver routing changes and was dropped. Because of the range of the E95 trucks and the lack of fueling facilities en route, the E95 trucks returned to the ADM plant in Decatur every night. The diesel control truck was occasionally driven to overnight destinations because of its extended range and the availability of diesel fuel.

The ethanol engines were of the same DDC design as the diesel engine used for comparison. However, the engines were modified so they could run on E95: DDC changed the electronic control system, enlarged the holes in the fuel injectors, added a glow plug to assist ignition during cold starts, and increased the compression ratio (from 18:1 for diesel to 23:1 for E95).

Because ethanol has a lower energy content than diesel fuel, ethanol trucks require larger fuel tanks to achieve the same range as a diesel truck. However, the E95 trucks had the same size fuel tanks as the diesel truck (two 120-gallon fuel tanks). Thus, the E95 trucks had a range of about 780 miles, which was more than sufficient for daily driving routes, but less than the 1,345-mile range of the diesel truck. Because ethanol is a liquid fuel dispensed similarly to diesel fuel, fueling the trucks was quick and easy.

Maintenance and Repair Issues

ADM Trucking operates an on-site general maintenance facility. Engineers and field support staff from DDC held a training seminar for the ADM mechanics when the project began. The training included a new service manual on the E95 engines, a review of the key components of the system, and a field troubleshooting course.

One of the E95 trucks logged more than 325,000 miles without a major engine overhaul. However, operational issues are inevitable with any new technology, and the DDC ethanol engines were no exception. The two main problems related to the alcohol engines: injector plugging and glow plug failure.

The problem with the fuel injectors was first discovered by the drivers, who reported low power and poor acceleration. Installing a

new set of injectors dramatically increased engine performance. Examination of the injector tips revealed fouling with a gummy, black deposit that restricted the fuel flow and the ability of the injector to atomize the fuel properly for complete combustion in the cylinder. The exact cause of the deposit is being investigated. All six fuel injectors were replaced more than once on each of the E95 trucks. In all, 14 sets of injectors were used in the four trucks. At almost $1,000 per set, this represented a significant expense. The average life of the fuel injectors was about 60,000 miles, but the actual life varied considerably, from about 19,000 miles to nearly 100,000 miles.

E95 and Diesel Fuel Cost Comparison
(dollars per gallon)

	E95 Ethanol Fuel	Diesel Fuel
Average Base Cost	$1.18	$0.58
Federal Alcohol Tax Credit	–$0.513	n/a
Subtotal	$0.667	$0.58
State Motor Fuel Tax (Illinois)	$0.19	$0.19
Federal Motor Fuel Tax	$0.184	$0.2440
State Sales Tax (6.25%)	$0.0417	$0.0363
Total Cost per Liquid Gallon (excludes delivery charges and dealer profit)	$1.08	$1.05
Total Cost per Diesel-Equivalent Gallon	$1.80	$1.05

Because ethanol does not autoignite easily, a glow plug was installed in each cylinder to aid in starting the ethanol compression ignition engines. A glow plug is similar to a spark plug except that it provides a constant hot surface rather than an intermittent spark. The glow plugs were turned on for one minute to heat the upper cylinder before the engine was started, and they remained on until the engine coolant reached normal operating temperature. Occasionally, one of the glow plugs burned out, or the tip of the plug broke off. Although these failures were relatively infrequent, they present a durability challenge that engine manufacturers are working to overcome. Eleven of the 24 glow plugs in the E95 trucks were replaced.

Cost

The cost of the fuel represents about 20% of the overall cost of owning and operating a heavy truck. This fuel cost is strongly affected by state and federal taxes. In operating its ethanol trucks, ADM benefitted from the Federal Alcohol Tax Credit, which allows a $0.54 per gallon income tax credit for 100% ethanol. Because ADM used E95, its tax credit was $0.513 per gallon, which brought the average fuel cost to about $0.67 per gallon of E95. This tax credit and the difference in state and federal tax rates led to an E95 fuel cost that was nearly the same, gallon for gallon, as that for diesel. On an energy-equivalent basis, however, the E95 fuel

was about $0.75 per diesel gallon equivalent (DGE) more expensive than diesel. During the course of the project, the average fuel cost was $1.05 per gallon for diesel (including tax).

The fuel cost per mile traveled depends on both fuel cost and fuel economy. On average, the fuel cost for the E95 trucks was about $0.32 per mile compared with $0.18 per mile for the diesel trucks.

The oil and filters are changed at approximately the same intervals on both kinds of trucks, but they are of different types. Oil for the E95 trucks cost $28.00 per oil change compared with $20.50 for the diesel truck; oil filters were $35.62 for the E95 trucks compared with $8.48 for the diesel unit. The combined cost of primary and secondary fuel filters for the E95 trucks was $48.34 compared with $6.30 for the diesel fuel filters. Therefore, on the E95 trucks the cost of an oil change and filter was $34.64 more and the fuel filters were $42.04 more than on the diesel truck. All other repair, maintenance, and inspection costs are considered normal fleet wear-and-tear items that are incurred on any truck, regardless of fuel type.

Taking maintenance, repair, and fuel into account over 300,000 miles, the additional costs of operating an E95 truck would be $1,500 for fuel, $1,732 for oil changes (one every 6,000 miles times $34.64), $252 for fuel filter changes (one every 50,000 miles times $42.04), and $5,000 for replacement electronic fuel injectors (60,000 miles of usable injector life at $1,000 per set). The total additional operating costs per E95 truck would be $8,484 per 300,000 miles.

Emissions

The in-use emissions levels of heavy trucks can be approximated by a chassis dynamometer. A chassis dynamometer puts the whole vehicle through a specific driving cycle and measures the emissions from the tailpipe. Unfortunately, no accepted standard driving cycle exists for chassis dynamometer testing of heavy trucks. Although a standard cycle, called the central business district (CBD) cycle, is an accepted cycle for buses, many large trucks with manual transmissions cannot perform the rapid accelerations and braking requirements of the CBD. Developing a more appropriate test cycle for heavy trucks is the object of several ongoing research projects. In the interim, West Virginia University (WVU) has designed a "5-peak" driving cycle that can be driven by most heavy trucks.

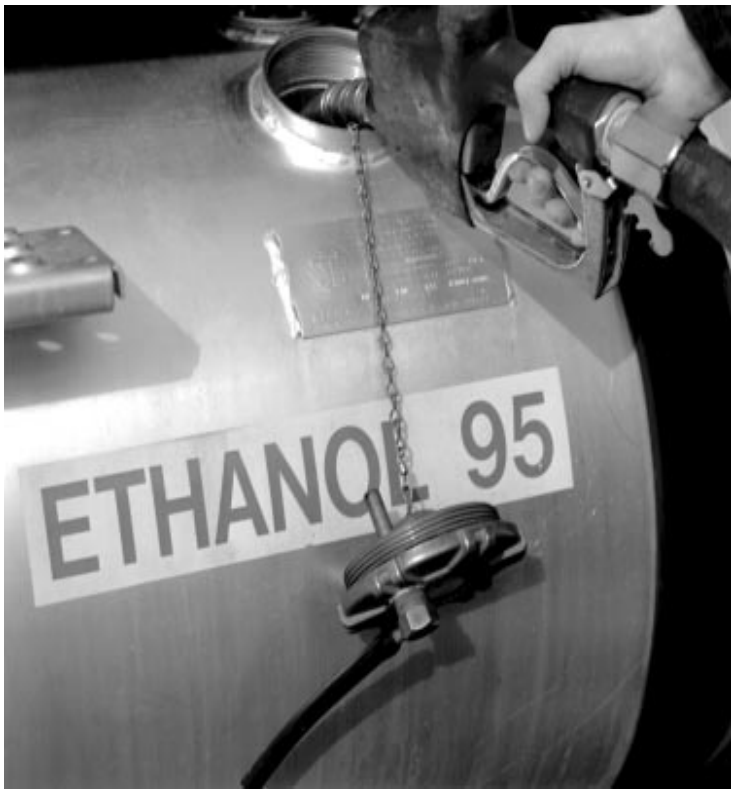
In 1995 and 1996, WVU tested the ADM trucks by using the 5-peak test cycle. The average particulate matter (PM) emissions from the E95 trucks were less than half those from the diesel truck. The average NO_x emissions from the E95 trucks were marginally lower than those from the diesel truck. Surprisingly, the average hydrocarbon (HC) and carbon monoxide (CO) emissions from the E95 trucks were higher than those from the diesel truck.

The U.S. Environmental Protection Agency and the California Air Resources Board require that new engines be emissions certified by standard procedures on engine (rather than chassis) dynamometer tests. During an engine dynamometer test, the engine is put on a test stand and run through specific loads and speeds while the exhaust emissions are measured. In January 1996, an E95 engine was removed from an ADM truck and installed on an engine dynamometer for this type of test. The results of the test were compared with certification data for the diesel version of the same engine.

The emissions results from engine dynamometer tests show the same trends as those from the chassis dynamometer tests: the E95 engine produced fewer PM and NO_x emissions, but more HC and CO emissions. Both the engine and chassis dynamometer tests show that ethanol engines can substantially reduce emissions, but emissions strongly depend on engine technology and vehicle condition.

Where Do We Go from Here?

The ADM project and others like it have demonstrated that ethanol can be used to power large trucks. Technical issues remain, but the barrier to wider ethanol use is more economic than technical. Operational costs, related to the cost of the ethanol engine, price of E95 fuel, and special ethanol components, are higher than those for conventional diesel engines. Because the trucking industry operates with a tight profit margin of about 2%, its fuel choice depends on cost. As Bill Peerenboom, vice president of the American Trucking Association's Foundation has pointed out: "The only way a fuel will compete on a long-term basis is on its economics." Several research projects are working toward low-cost ethanol production from a variety of feedstocks. When the cost differential between ethanol and diesel fuel becomes more favorable for ethanol, we will see more ethanol trucks on the nation's highways.



Specifications of the ADM Ethanol Trucks

Fuel: 95% ethanol (ethyl alcohol), 5% gasoline; Lubrizol added to improve lubrication (0.06%)

Curb weight: 23,688 pounds

Gross vehicle weight rating: 80,000 pounds

Chassis: White-GMC WIM-64T Class 8 line-haul truck

Engine: Detroit Diesel Corporation 6V-92TA
6-cylinder, 2-cycle engine
Compression ignition with glow plug assist
Compression ratio: 23:1
Rated horsepower: 300 at 2,100 rpm
Rated torque: 975 ft-lb at 1,200 rpm
1992 EPA Emissions Certified

Fuel tanks: Two 120-gallon stainless steel tanks

For further information, contact:

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Further Information on the World Wide Web

The Ethanol Heavy-Duty Truck Fleet Demonstration Project – Final Report by N.J. Marek, http://www.afdc.doe.gov/demoproj/hdv/htitle.html

Guidebook for Handling, Storing & Dispensing Fuel Ethanol, http://www.es.anl.gov/pdfs/ethanolguidebook.pdf

Biofuels Update Quarterly Newsletter, http://www.afdc.doe.gov/bionews

These reports can also be obtained from the National Alternative Fuels Hotline by calling 1-800-423-1363.

For more information on the availability of ethanol engines, contact:

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This brochure has been reviewed by representatives of vehicle manufacturers, fuel providers, fleet operators, and federal and state governments.

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Disclaimer

This case study is intended only to illustrate approaches that organizations could use in adopting AFVs in their fleets. The data cited here, although real experience for the fleet discussed in this case study, may not be replicated for other fleets. For more comprehensive information on the performance of AFVs and other related topics, please call (800/423-1363) or e-mail (hotline@afdc.nrel.gov) the National Alternative Fuels Hotline. To learn more about DOE's role in alternative-fuel vehicle research, visit the Alternative Fuels Data Center on the World Wide Web at http://www.afdc.doe.gov.

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